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Streamlined Aquatic Ecological Risk Evaluation for Tiger Tunnel
Leadville, Colorado

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Within the LFPG, runoff from the Tiger Complex waste piles and direct AMD from the Venture Cabin Shaft (Venture Complex; West Fork LFPG) and the Tiger Tunnel (East Fork LFPG) are the primary sources of metal loading (Matrix 2005). While it is projected that remediation of the Venture Complex will occur, the LFWWG has prioritized cleanup of the Tiger Complex within Colorado Gulch (LFWWG 2010). The LFWWG's strategy is to systematically remediate the Lake Fork watershed from upstream contaminant sources (i.e., Sugarloaf Gulch) to downstream sources (i.e., Colorado Gulch). The EE/CA prepared by the BLM (2006a) to assess potential cleanup operations at the Tiger Complex recommended that two waste piles be removed and capped and that hydrologic controls be implemented. These recommended actions were carried out in 2010. The EE/CA also considered the construction of a SRB in the event that these operations did not significantly reduce AMD emanating from the Tiger Tunnel. Noticeable improvements in AMD from the Tiger Tunnel have not occurred based on available data, so the potential water quality improvements associated with a SRB are currently receiving greater attention.

2.1 Site Setting

The Tiger Tunnel is located in the foothills of the Sawatch Range in the Colorado Rocky Mountains at the upper reaches of the Arkansas River valley. Elevation ranges from 10,800 ft at the Tiger Tunnel to 9,600 ft at Lake Fork. Vegetation in and around the site is predominantly lodgepole pine (*Pinus contorta*), with some spruces (*Picea* sp.) and fir (*Pseudotsuga menziesii* and/or *Abies lasiocarpa*). Grasses, sedges, and sagebrush (*Artemisia* sp.) dominate the lower portions of Lake Fork watershed. The area immediately surrounding the Tiger Tunnel is primarily mine waste rock/tailings and generally free of vegetatio. Below the Tiger Tunnel are four settling ponds. These ponds receive Tiger Tunnel discharge and are located within the footprint previously occupied by waste pile TC-8 prior its removal in 2010. South of Tiger Tunnel is the on-site repository where material from piles TC-7 and TC-8 is currently located and capped.

Downstream of the Tiger Tunnel, near the confluence of Colorado Gulch and Lake Fork, is a 3.6 acre wetland. The wetland has received a high degree of sedimentation from upstream mine waste piles, unimproved roads, and weathered bedrock outcrops (LFWWG 2010). Aside from water sampling and analysis at points upstream and downstream of the wetland in Colorado Gulch, little information about the wetland and how it affects metal loading to Lake Fork is available. The Lake County Open Space Initiative is currently exploring the possibility of entering into a conservation easement agreement with the wetland landowner as a means of protecting the area in perpetuity.

The Lake Fork watershed has an annual mean temperature of 36°F with highs in January and July ranging 25-35°F and 75-82°F, respectively. The mean annual precipitation for the watershed ranges from 20 inches in the lower reaches to over 35 inches in the higher reaches. Monthly maximum precipitation usually occurs in March and April, with secondary peaks in July and August reflecting the influence of summer monsoon. Average annual snowfall is approximately 150 inches in the lower reaches and over 300 inches near the headwaters. The watershed typically experiences 10-75 frost-free days.

2.2 Hydrology

The Lake Fork is a tributary of the Arkansas Headwater Basin. The Lake Fork Watershed drains about 75 square miles and includes all or part of the Turquoise Lake, Willow Creek, Halfmoon Creek, and Leadville City Hydrologic Units. Lake Fork is fed by several tributaries including Bartlett Gulch, Sugar Loaf Gulch, Siwatch Tunnel, Strawberry Gulch, Colorado Gulch, Hunt Gulch, Rock Creek, Willow Creek, and Halfmoon Creek (Figure 1). The drainage area for LFPG above the Tiger Complex is approximately 0.43 square miles (Matrix 2005). Lake Fork is largely controlled by releases generated by the US Bureau of Reclamation Sugarloaf Dam facility. Lake Fork and its tributaries also demonstrate seasonal flow regimes determined by snowpack and summer storm runoff. Peak flow of the Lake Fork generally occurs from mid-May to mid-June. Total Lake Fork base flow discharge near its confluence with the Arkansas River is approximately 14,000 acre-feet for the months of September through March and approximately 22,000 acre-feet for April through August (LFWWG 2010).

In September 2001, Walton-Day et al. (2005) determined that stream flow immediately below Sugarloaf Dam averaged 8.3 cubic feet per second (cfs) but declined to 6.0 cfs at a sampling site downstream of the Colorado Gulch confluence. Lake Fork, upstream of its confluence with Halfmoon Creek, averaged 32.0 cfs indicating that approximately 75% of Lake Fork flow upstream of this confluence is generated from Hunt and Willow Creeks.

The Tiger Tunnel is located in the East Fork LFPG which joins the West Fork LFPG prior to flowing into Colorado Gulch (Figure 2). The lower section of Colorado Gulch has perennial flow and the central and upper sections have intermittent flow (Fisher 2006). CMC found in May 2003 (high flow) that the East Fork and the West Fork of LFPG (above the Venture Complex) generated 0.42 and 0.52 cfs, respectively (CMC, 2004). Although flow was similar in the East and West Forks, the zinc and copper loads from the East Fork, were approximately 4 and 200 times, respectively, greater than those from the West Fork. More recent data collected during three events in June 2010 indicate that average zinc and copper loads from the East Fork were 2 and 42 times, respectively, greater than those loads from West Fork (below the Venture Complex).

The Venture Complex is located along the West Fork LFPG, near its confluence with the East Fork LFPG. The Venture Complex consists of the Venture Cabin Shaft and several mine waste piles. Unlike the East Fork, the West Fork LFPG flows throughout the year. During high flows, water infiltrates the Venture Cabin Shaft and causes it to overflow (LFWWG 2010). Water collected from a seep at the toe of the furthest downstream waste pile in May 2003 had concentrations of dissolved cadmium, copper, and total aluminum of 43 µg/L , 70 µg/L and >50,000 µg/L, respectively (CMC 2004). The Venture Complex was identified by the LFWWG (2010) as a source of metal contamination that warrants the completion of a site-specific EE/CA.

Heavy metals entering the Lake Fork watershed from Colorado Gulch originate by leaching of eroded mine waste in the stream channel, direct leaching of mine waste piles, mine drainage, and leaching of un-mined sources (Fisher 2006). While these metal sources exist, the impact of Colorado Gulch on the water quality in Lake Fork is highly variable and dependent on flow regime. Under high flow conditions, Colorado Gulch was shown to contribute 46% of the total

flow and 80% of the total zinc load to the Lake Fork (CMC 2004). During low flow conditions, however, Colorado Gulch contributes only 1.4% of the flow and 5% of the total zinc load to the Lake Fork (CMC 2004). Walton-Day et al. (2005) similarly noted during low flow conditions (i.e., September 2001) that the concentration of zinc in Lake Fork was not highly influenced by inflows from Colorado Gulch. The study noted that Reaches 1 and 3, neither of which contained inflow from Colorado Gulch, were the highest contributors of aluminum, copper, iron, lead, manganese, and zinc to Lake Fork.

2.3 Aquatic Setting

The upper Arkansas River, from it confluence with Lake Fork downstream to Parkdale, was recently recognized by Colorado Parks and Wildlife as supporting a Gold Medal trout fishery (CPW 2014). The designation recognizes the transformation of this previously impaired river reach into to one of the most popular fishing destinations in the state. The Lake Fork provides adequate physical habitat to support a healthy trout fishery, but its actual biomass is indicative of a water quality impaired system (BLM 2006a). Davies and Policky (1994) and Policky (2006) found that brown (*Salmo trutta*) and brook trout (*Salvelinus fontinalis*) exist in the Lake Fork. Brown trout dominated the Lake Fork from its confluence with the Arkansas River, upstream to Halfmoon Creek. Brook trout dominated Lake Fork from Rock Creek through an area downstream of Colorado Gulch, where biomass was reduced by 90%. Young of year fish were not found in Lake Fork by Davies and Policky (1994), indicating that successful brown or brook trout reproduction was not occurring. Twelve years later, Policky (2006) found that brown trout had become the dominant fish species upstream of Rock Creek and that they were reproducing and recruiting in the Lake Fork from the Arkansas River to the inflow of Colorado Gulch. Historically, Greenback cutthroat trout (*Onchorynchus clarki stomias*) occurred in the Arkansas River watershed. They have been reintroduced in some areas of the Lake Fork watershed including Rock Creek on the FWS Leadville National Fish Hatchery, Mill Creek above Turquoise Lake, and Timberline and Virginia Lakes (Figure 1).

Brook trout have been observed in Colorado Gulch, upstream of its confluence with LFPG, but formal fish surveys, as well as benthic macroinvertebrate surveys, have not been conducted in Colorado Gulch or its tributaries (LFWWG 2010). Similar observational information suggests that no aquatic life exists in the East Fork LFPG, likely due in part to Tiger Tunnel discharges (LFWWG, 2010), but it is likely that the lack of aquatic life is, in part, due to habitat limitations. Aquatic habitat in the West Fork LFPG is likewise limited and impacted by discharges from the Venture Complex. Analogous to the East Fork LFPG, this tributary is not known to support aquatic life. Despite this lack of data within Colorado Gulch, Nelson and Roline (2000) determined that the Lake Fork, downstream of Colorado Gulch, posed the greatest toxicological risk to hyporheic invertebrates.

3.0 Technical Approach

The first step of the approach was to identify water bodies of concern and the relevant species that are likely impacted by the Tiger Tunnel discharge. The total flow and metals concentrations

from Tiger Tunnel, Colorado Gulch, and Lake Fork were measured in order to estimate the metals loading in this system. Loading is a direct function of the metal concentration and flow in a waterway and is typically expressed in terms of pounds of material transported per day (lbs/day). This information was then evaluated with reference to relevant water quality standards to gauge the potential impacts to downstream aquatic habitats. The overall objective of this approach is 1) to determine if the metal loading from Tiger Tunnel is expected to impact downstream aquatic life; and 2) to estimate the potential effect on aquatic life if metal loading/discharges from Tiger Tunnel are eliminated.

3.1 Conceptual Site Model

A conceptual site model was developed to illustrate transport pathways of contaminants of concern to potential aquatic ecological receptors (Figure 3). When developing models for theassessment, numerous variables, including species likely to be affected downstream; metals loading (lbs/day) from Tiger Tunnel to LFPG, Colorado Gulch, and Lake Fork; metals concentrations in Tiger Tunnel adit discharge water; Table Value Standards; and trout-specific toxicity thresholds were considered.

3.2 Water Quality Data

Water quality and flow measurement data evaluated for this assessment were collected USGS and CMC on 16 total occasions from 2006 – 2011 (Table 1). Surface water quality data was collected by the USGS in June, July, August, and October 2006 and in June and September in 2010 and 2011. Surface water quality data was collected by CMC in May, June, and August 2009, May and June 2010, and June 2011. Historical sampling sites are presented in Figure 2. Sites include locations directly below the Tiger Tunnel discharge (i.e., TT-00, LFPE-00); in Colorado Gulch, upstream of its confluence with Lake Fork (i.e., CG-01, COG-12); and in Lake Fork, immediately downstream of its confluence with Colorado Gulch (i.e., LF-08).

Table 1: Tiger Tunnel, Colorado Gulch, and Lake Fork sampling summary by agency and dates.

Agency	Sampling Dates
USGS	June 7, 2006; July 7, 2006; August, 24, 2006; October 23, 2006 June 10, 2010; September 29, 2010; June 8, 2011; September 28, 2011
CMC	May 18, 2009; May 26, 2009; June 9, 2009; August 31, 2009 May 25, 2010; June 1; 2010; June 17, 2010; June 14, 2011

USGS: U.S. Geological Survey; CMC: Colorado Mountain College

Water sampling and flow measurements followed methods described in Sampling Analysis Plans (USGS 2009; CMC 2011). For each sampling event, duplicate samples were collected at a rate of 10% and one field blank sample was collected by each sampling team on each sampling day. Each sample was preserved with nitric acid and transported to the analytical laboratory. USGS samples were analyzed by the University of Southern Mississippi with ICP/MS according to Environmental Protection Agency, Method 6020A (EPA 2007). CMC samples were analyzed by

the Timberline Analytical Laboratory with ICP/OES according to Method 6010C (EPA 2007). Cadmium, copper, zinc, aluminum, lead, manganese, and arsenic were quantified in all samples.

3.3 Metal Loading Data

Metal loading at each sampled site for each of the 16 sampling events was calculated based on Equation 1 and percent loading at downstream sites due to upstream loading contributions was calculated according to Equation 2. We estimated changes in surface water concentrations of metals at downstream locations (i.e., Colorado Gulch and Lake Fork) with the removal of Tiger Tunnel inputs according to Equation 3. This approach includes mass balance assumptions including a 'pound for pound' removal of metals at the source versus downstream locations. These methods are similar to those utilized by CMC (2004) and EPA (2012).

Equation 1: Loading (lbs/day) = $(C \cdot (6.24 \times 10^{-8})) \cdot (Q \cdot (8.46 \times 10^{4}))$
Where:
C = Metal concentration (μg/L);
Q = Flow (cfs).

Equation 2: Percent load (%) = L_u/L_d
Where:
L_d = Downstream metal load (lbs/day);
L_u = Upstream metal load (lbs/day).

Equation 3: $C_d = ((L_d - L_u)/(Q_d - Q_u) \cdot 8.46 \times 10^{4}) / (6.24 \times 10^{-8})$
Where:
C_d = Downstream concentration (μg/L);
Q_d = Downstream flow (cfs);
Q_u = Upstream flow (cfs).

3.4 Toxicity Threshold Values

To gauge impacts associated with measured water quality and theoretical downstream improvements with the removal of Tiger Tunnel loading, we compared concentrations of cadmium, copper, zinc, lead, manganese, arsenic, and aluminum to applicable Table Value Standards (TVS) for the protection of aquatic life (CDPHE 2011).

We also compared measured and predicted concentrations of cadmium, copper, and zinc to hardness-based, trout-specific toxicity values. These values were derived through the use of a toxicity threshold model (A. Todd, unpublished trout-specific toxicity calculator) based entirely on acute and chronic toxicity studies for select metals and salmonid species resident in Colorado (brook trout, brown trout, and rainbow trout). This model was constructed according to water quality criteria development methods described by Stephen et al. (1985).

Table Value Standards and trout toxicity threshold values were calculated for Colorado Gulch and Lake Fork based on the average of the measured and predicted (i.e., metal concentration after the calculated removal of Tiger Tunnel inputs) hardness values in each. Colorado Water Quality Standards are typically much lower than the toxicity threshold values for trout because TVS are designed to be highly conservative and protective of the most sensitive aquatic species reported in toxicological literature. Toxicity thresholds for resident trout species provide more representative threshold concentrations for the aquatic resources in this study.

4.0 Results and Aquatic Risk Characterization

Water quality data from 16 sampling events for Tiger Tunnel and Colorado Gulch, and three sampling events for Lake Fork were used to assess aquatic risk in this system. Measured and predicted concentrations of metals in Colorado Gulch and Lake Fork were compared to acute and chronic TVS and hardness-based trout-specific toxicity threshold values to assess water quality improvements with the arithmetic removal of Tiger Tunnel discharge.

4.1 Tiger Tunnel

Measured flow from Tiger Tunnel ranged from 0.0002 – 0.245 cfs with the lowest flow recorded in late September 2010 and the highest flow recorded in mid-June 2011 (Table 2). Concentrations of most metals in Tiger Tunnel discharge were highest during low-flow periods of the year (August, September) and lowest during high-flow, spring run-off periods (May, June; Table 3, Figures 4-10). Lead is the exception, in that it displayed its highest concentrations during high-flow events and its lowest concentrations during low-flow periods (Table 3, Figures 4-10). Loading levels in Tiger Tunnel discharge exhibited peaks during spring run-off periods and lows during fall months for all metals (Table 4, Figures 4-10).

Aquatic habitat is not present within the Tiger Tunnel outflow, therefore comparison of water quality data are not directly applicable with reference to TVS and trout-specific toxicity thresholds. A comparison of the detected concentrations to TVS is provided in order to provide a relative perspective of the water quality coming out of the tunnel (Table 3). The results indicate that all metals are above TVS and suggest that aquatic species would be at risk if the Tiger Tunnel discharge were present in aquatic habitat.

4.2 Colorado Gulch

Flows in Colorado Gulch, above its confluence with Lake Fork ranged 0.23 – 43.66 cfs with the lowest flow recorded in late August 2006 and the highest flow recorded in mid-June 2011 (Table 2). Concentrations of all metals measured in Colorado Gulch were highest during spring high-flow periods and lowest during the low-flow events (Table 5, Figures 4-10). Metal loading followed a similar pattern in that the highest loads in Colorado Gulch occurred during spring run-off events (Table 6, Figures 4-10). This pattern may be indicative of this system's tendency

to flush metals during high flows from perennial AMD sources and snowmelt-driven surface flows.

Table value standards and brown trout toxicity threshold values for Colorado Gulch are presented in Table 7. Measured concentrations of cadmium, copper, zinc, and aluminum frequently exceeded chronic and acute TVS for aquatic life for all sampling events. Lead and manganese exceeded these standards less frequently and arsenic concentrations did not exceed TVS. For the trout thresholds, cadmium exceeded the hardness-based LC50 values (0.78 µg/L) for trout in all sample concentrations that were reported above the detection limit. Copper and zinc exceeded the hardness-based LC50 values (copper: 17.4 µg/L; zinc: 113 µg/L) in six and eleven Colorado Gulch samples, respectively.

The calculated percentage of metal loading from Tiger Tunnel to Colorado Gulch was generally highest in August 2006 and September 2011 and lowest in June 2011 and May 2010 (Table 8).

High load percentages (i.e., > 100%) coincide with low flow periods and may reflect a breakdown in the assumption that the flow from Tiger Tunnel reaches Colorado Gulch. Mathematically, these scenarios arise from situations where loading at upstream sites (e.g., Tiger Tunnel) are greater than loading at downstream sites (e.g., Colorado Gulch).

Concentrations of metals in Colorado Gulch using modeling assumptions that account for removal of Tiger Tunnel inputs are presented in Table 9. Modeling the removal of Tiger Tunnel discharge to Colorado Gulch shifted water quality from exceeding TVS for aquatic life to reaching these standards in four of 112 cases (e.g., metal concentration on a given date) in Colorado Gulch. The removal shifted water quality from exceeding toxicity threshold values for trout to reaching these thresholds in five cases in Colorado Gulch.

4.3 Lake Fork

Flows in Lake Fork were only recorded on three occasions in 2010 and ranged from 30.2 – 65.3 cfs. The lowest flow measurement was taken prior to peak snowmelt runoff in May, while the highest flow measurement was recorded seven days later in early June (Table 1). Metals were highest at the Lake Fork sampling site during the May 2010 sampling event (Table 10, Figures 4-10). Only zinc and manganese were detected in each of the three samples collected from Lake Fork in 2010. Metal loading in Lake Fork was highest in May 2010 and particularly pronounced for cadmium, copper, zinc, and manganese at that time (Table 11, Figures 4-10).

Table value standards and the toxicity threshold values for brown trout for Lake Fork are presented in Table 12. Measured concentrations of zinc exceeded the acute TVS in each of the three samples collected from Lake Fork. Cadmium and copper exceeded the acute TVS in the May 2010 samples. Aluminum exceeded the acute TVS in May 2010 and the chronic TVS on June 1, 2010. Manganese exceeded the chronic TVS in May 2010. Lead and arsenic were below detection limits in each of the three sampling events. The hardness-based LC50 values for cadmium (0.58 µg/L), copper (6.6 µg/L), and zinc (77 µg/L) were exceeded in Lake Fork in May 2010.

The calculated percentage of metal loading from Tiger Tunnel within Lake Fork was generally at or below 10% for all metals during the three available sampling events (Table 13). Aluminum, manganese, and zinc each exhibited an increase in the percent loading from Tiger Tunnel over the sampling events. Concentrations of metals in Lake Fork with the modeled removal of Tiger Tunnel inputs are presented in Table 14. Modeling the removal of Tiger Tunnel discharge to Lake Fork did not shift water quality from exceeding TVS or toxicity threshold values for trout to reaching these benchmarks in any of the 3 cases.

4.4 Loading Uncertainty

Noticeable anomalies occur in the data presented in Tables 9 and 14 in terms of 'predicted' concentrations of several metals after the modeled removal of Tiger Tunnel discharge (i.e., negative predicted concentrations). These cases tend to highlight a breakdown in the assumption of flow connectivity that must be met when manipulating loading data within a drainage. For example, during seasonal low-flow periods (July, August, and September) several 'predicted' concentrations are negative indicating that Tiger Tunnel surface discharge is not reaching Colorado Gulch or Lake Fork. Conversely, during seasonal high flow periods (May, June), 'predicted' concentrations are more reasonable suggesting that the assumption of flow connectivity is met.

5.0 Conclusions and Discussion

The results of this evaluation indicate that although the Tiger Tunnel discharge has low pH levels and contains significantly elevated concentrations of aluminum, arsenic, cadmium, copper, manganese, lead, and zinc that are above both acute and chronic Table Value Standards, as well as trout-specific toxicity thresholds, the load from the Tiger Tunnel is a minor contributor to the overall load on the downstream aquatic habitats with existing fish populations. Based on model calculations, the complete removal of Tiger Tunnel discharge does not result in significant improvement of water quality in Colorado Gulch and Lake Fork.

Although adit flow contains extremely high levels of trace metals, its apparent inability to transfer much of this load downstream is likely due its very low discharge rate and only seasonal connectivity with Colorado Gulch and Lake Fork. Walton-Day et al. (2005) also found significant metal attenuation within the Lake Fork drainage. The authors found that a beaver pond near the mouth of Colorado Gulch removed approximately 10% of the Lake Fork's aluminum and copper load, 20% of its zinc load, and 15% of its manganese load. They also found that the wetland below another draining adit in the Sugar Loaf district (i.e., the Siwatch Tunnel) removed approximately 75-90% of the adit's load of aluminum, iron, manganese, and zinc. While that study did not detail load reductions in LFPG or Colorado Gulch, it serves to highlight natural factors that tend to reduce metal loads in this system. Additional studies would be needed to evaluate 1) the attenuation characteristics in this drainage and the potential role of the wetland located near the confluence of the Colorado Gulch and Lake Fork; and 2) the

seasonal connectivity of Tiger Tunnel discharge and downstream reaches in the surface water and groundwater matrices.

The loading model predicted that a complete removal of the metals contribution being discharged from the Tiger Tunnel would not result in a significant reduction of metals in the downstream Lake Fork and Colorado Gulch and related trout fishery. However, there is a high degree of uncertainty related to metals contributions in runoff and groundwater associated with the Tiger Complex, especially during spring runoff or other high flow or surge events. Thus, while the model predicts that the metals contributions to the downstream fisheries from the adit at Tiger Tunnel are minimal, it must be noted that the metals concentrations in the Tiger Tunnel adit discharge are significantly above acute toxicity thresholds related specifically to trout species and changes in water quality and associated risks due to mine surges or mine blows out could impact the fishery in Lake Fork.

Although metal loading from East Fork LFPG is consistently higher than that of the West Fork LFPG, it should also be noted that ongoing loading from the Venture Complex and other sources may pose similar risks to Colorado Gulch and Lake Fork water quality. While we determined with available data that metal loading from the Tiger Tunnel does not greatly influence Lake Fork water quality, similar modeling would be required to determine if the same holds true for metal inputs from the Venture Complex.

While there is high confidence that Tiger Tunnel effluent has very high metals concentrations and low flows, it is uncertain how influential that discharge is relative to metals concentrations in the Lake Fork and Colorado Gulch at certain times of the year. Therefore, uncertainty associated with this model is considered moderate due to the relatively small data set, the inherent variability of those data through time, and other factors. These factors include:

- The connectivity between Tiger Tunnel discharge and surface water at the mouth of Colorado Gulch and Lake Fork is questionable outside of the seasonal high flow period.
- The degree to which simple attenuation in this system reduces Tiger Tunnel loads to downstream locations is unknown and would require further study to elucidate.
- The interaction between surface water and groundwater fluxes of metals in this system is unknown and would require further study to elucidate.
- At times when Tiger Tunnel discharge does not reach surface water at the mouth of Colorado Gulch or Lake Fork, our calculations of metal load and concentration reductions are not applicable.
- Although data collected over a span of five years were considered for Colorado Gulch, data was absent from several months during each year. Data gaps exist for winter and early spring potentially missing highest metals concentrations expected during low-flow winter months and pulses of metal loading during early spring.
- Data for modeling metals loading in Lake Fork from the Tiger Tunnel was sparse. Only one year consisting of three sampling events was usable.
- The assessment only considers Tiger Tunnel discharge to the drainage and not other sources including those within the Venture Mine Complex,
- Fish toxicity values may not completely apply to fish that may reside in (or be introduced to) Colorado Gulch or Lake Fork due to developed resistance or high sensitivity.

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7.0 Tables

Table 2: Measured flow at Tiger Tunnel[a], Colorado Gulch[b], and Lake Fork[c].

	Flow (cfs)		
Date	Tiger Tunnel	CO Gulch Mouth	Lake Fork
6/7/2006	0.02	14	NA
7/12/2006	0.01	1	NA
8/24/2006	0.0032	0.23	NA
10/23/2006	0.0025	0.93	NA
6/10/2010	0.042	17	NA
9/29/2010	0.0002	0.36	NA
6/8/2011	0.18	28	NA
9/28/2011	0.043	0.57	NA
5/18/2009	0.223	11.990	NA
5/26/2009	0.095	21.980	NA
6/9/2009	0.083	10.722	NA
8/31/2009	0.002	1.220	
5/25/2010	0.14	11.24	30.2
6/1/2010	0.15	19.51	103
6/17/2010	0.0208	13	65.33
6/14/2011	0.245	43.66	NA

[a] Sites TT-00 (USGS) and LFPE-00 (CMC) located immediately below the Tiger Tunnel discharge.

[b] Sites CG-01 (USGS) and COG-12 (CMC) located in Colorado Gulch, immediatedly upstream of its confluence with Lake Fork.

[c] Site LF-08 (CMC) located in Lake Fork, immediately downstream of its confluence with Colorado Gulch.

NA: Analyte not quantified.

Table 3: Measured metal concentrations at Tiger Tunnel. Values are dissolved concentrations unless otherwise noted.

Date	Cd (ug/L)	Cu (ug/L)	Zn (ug/L)	Al (ug/L, tot.)	Pb (ug/L)	Mn (ug/L)	As (ug/L)
6/7/2006	**376**	**4510**	**8870**	**32400**	**180**	**8610**	**677**
7/12/2006	**547**	**5130**	**23800**	**64000**	**116**	**22700**	**701**
8/24/2006	**648**	**6050**	**29300**	**43600**	**99**	**27800**	**732**
10/23/2006	**848**	**6680**	**28000**	**91500**	**104**	**24400**	**767**
6/10/2010	**247**	**3840**	**12800**	NA	**152**	**12300**	**585**
9/29/2010	**789**	**6510**	**25500**	**76200**	**95**	**23800**	**751**
6/8/2011	**28.8**	**750**	**4790**	**16100**	**26**	**3270**	55
9/28/2011	**173**	**1250**	**27300**	**75900**	**21**	**24600**	111
5/18/2009	**180**	**4809**	**8767**	**27320**	**99**	**6432**	303
5/26/2009	**226**	**3884**	**8932**	**20480**	**118**	**8169**	**265**
6/9/2009	**427**	**4726**	**14170**	**39110**	**177**	**4613**	**539**
8/31/2009	**808**	**5427**	**15230**	**39320**	**94**	**17630**	**520**
5/25/2010	**35**	**746**	**1408**	**9586**	**16**	1088	97
6/1/2010	**22**	**568**	**1091**	**3108**	**11**	919	33
6/17/2010	**441**	**4923**	**14613**	**7609**	**185**	**12264**	**734**
6/14/2011	**176**	**3593**	**8394**	**25178**	**86**	**6386**	**213**

Bold values exceed chronic Table Value Standards for Tiger Tunnel.

Bold, underlined values exceed acute Table Value Standards for Tiger Tunnel.

NA: Analyte not quantified.

Table 4: Metal loading (pounds per day) at Tiger Tunnel. Values are based on dissolved concentrations unless otherwise noted.

Date	Cd (lbs/d)	Cu (lbs/d)	Zn (lbs/d)	Al (lbs/d, tot.)	Pb (lbs/d)	Mn (lbs/d)	As (lbs/d)
6/7/2006	0.041	0.487	0.957	3.495	0.019	0.929	0.073
7/12/2006	0.030	0.277	1.284	3.452	0.006	1.224	0.038
8/24/2006	0.011	0.104	0.506	0.753	0.002	0.480	0.013
10/23/2006	0.011	0.090	0.378	1.234	0.001	0.329	0.010
6/10/2010	0.056	0.870	2.900	NA	0.034	2.786	0.133
9/29/2010	0.001	0.007	0.028	0.082	0.000	0.026	0.001
6/8/2011	0.028	0.728	4.651	15.631	0.026	3.175	0.053
9/28/2011	0.040	0.290	6.332	17.604	0.005	5.706	0.026
5/18/2009	0.216	5.788	10.551	32.880	0.119	7.741	0.364
5/26/2009	0.115	1.989	4.575	10.489	0.060	4.184	0.136
6/9/2009	0.191	2.109	6.324	17.456	0.079	2.059	0.241
8/31/2009	0.009	0.059	0.164	NA	NA	0.190	0.006
5/25/2010	0.026	0.563	1.063	7.243	0.012	0.822	0.073
6/1/2010	0.018	0.459	0.883	2.516	0.009	0.744	0.027
6/17/2010	0.050	0.552	1.639	0.854	0.021	1.376	0.082
6/14/2011	0.233	4.748	11.092	25178	0.114	8.439	0.281

NA: Not applicable, concentration below detection limit or not quanitified.

Table 5: Measured metal concentrations in Colorado Gulch. Values are dissolved concentrations unless otherwise noted.

Date	Cd (ug/L)	Cu (ug/L)	Zn (ug/L)	Al (ug/L, tot.)	Pb (ug/L)	Mn (ug/L)	As (ug/L)
6/7/2006	**1.63**	**15.2**	**109**	**359**	**0.30**	152	0.0295
7/12/2006	**4.14**	**8.93**	**250**	**473**	0.04	342	0.0005
8/24/2006	**3.58**	**5.48**	**241**	**254**	0.11	322	0.0002
10/23/2006	**1.4**	**7.03**	**101**	**262**	0.15	116	0.0009
6/10/2010	**2.1**	**18.8**	**134**	**347**	**0.48**	199	0.0633
9/29/2010	**1.17**	**6.69**	**95**	**127**	0.21	97	0.0004
6/8/2011	**7.21**	**103**	**481**	**1290**	**2.10**	564	0.0423
9/28/2011	**1.48**	**7.39**	**100**	**150**	0.19	106	0.0008
5/18/2009	**9.51**	**115**	**602**	**1576**	<0.02	763	<0.002
5/26/2009	<0.01	**25**	**281**	**786**	<0.02	400	<0.002
6/9/2009	<0.01	**25**	**237**	**768**	<0.02	358	<0.002
8/31/2009	<0.01	<0.01	**134**	128	<0.02	203	<0.002
5/25/2010	**15.0**	**193**	**943**	**2626**	**7.0**	**1110**	<3.5
6/1/2010	<1	**7**	**44**	**100**	<4.3	64	<3.5
6/17/2010	**2.7**	**13**	**171**	**153**	<4.3	266	<3.5
6/14/2011	**5.2**	**32**	**301**	**694**	<10	386	<39

Bold values exceed chronic Table Value Standards for Colorado Gulch (see Table 7).

Bold, underlined values exceed acute Table Value Standards for Colorado Gulch (see Table 7).

Table 6: Metal loading (pounds per day) at Colorado Gulch. Values are based on dissolved concentrations unless otherwise noted.

Date	Cd (lbs/d)	Cu (lbs/d)	Zn (lbs/d)	Al (lbs/d, tot.)	Pb (lbs/d)	Mn (lbs/d)	As (ug/L)
6/7/2006	0.123	1.148	8.23	27.11	0.0227	11.48	0.0295
7/12/2006	0.022	0.048	1.35	2.55	0.0002	1.84	0.0005
8/24/2006	0.004	0.007	0.30	0.32	0.0001	0.40	0.0002
10/23/2006	0.007	0.035	0.51	1.31	0.0008	0.58	0.0009
6/10/2010	0.193	1.724	12.29	31.82	0.0440	18.25	0.0633
9/29/2010	0.002	0.013	0.18	0.25	0.0004	0.19	0.0004
6/8/2011	1.089	15.556	72.64	194.82	0.3172	85.18	0.0423
9/28/2011	0.005	0.023	0.31	0.46	0.0006	0.33	0.0008
5/18/2009	0.616	7.409	38.94	101.98	NA	49.34	NA
5/26/2009	NA	2.947	33.36	93.26	NA	47.46	NA
6/9/2009	NA	1.434	13.70	44.42	NA	20.69	NA
8/31/2009	NA	NA	0.88	NM	NA	1.34	NA
5/25/2010	0.910	11.691	57.17	159.29	0.4249	67.31	NA
6/1/2010	NA	0.702	4.66	10.56	NA	6.78	NA
6/17/2010	0.191	0.893	11.99	10.75	NA	18.66	NA
6/14/2011	1.217	7.442	70.79	551.00	NA	90.95	NA

NA: Not applicable, concentration below detection limit.

Table 7: Hardness-based[a] Table Value Standards (TVS) for aquatic life[b] and threshold toxicity values for brown trout[c] in Colorado Gulch.

	TVS (ug/L)		Trout Tox Value (ug/L)		
Metal	Acute	Chronic	LC50	Acute	Chronic
Cadmium	0.3	0.1	0.78	0.39	0.32
Copper	2.2	1.7	17.4	8.7	4.20
Zinc	27.8	21.1	113	56	69
Aluminum (tot.)	245.8	35.1	NA	NA	NA
Lead	7.6	0.3	NA	NA	NA
Manganese	1573	869	NA	NA	NA
Arsenic	340	150	NA	NA	NA

[a] Values based on average measured and predicted hardness in Colorado Gulch (14.62 mg/L as CaCO3; range: 1.46 - 60.7 mg/L as CaCO3; n = 16).

[b] Table Value Standards (TVS) from the Basic Standards and Methodologies for Surface Water, Aquatic Life (CDPHE 2011).

[c] Developed by USGS according to Stephan et. al (1985).

Table 8: Theoretical percent metal load at mouth of Colorado Gulch from Tiger Tunnel (Load ratio: Tiger Tunnel/Colorado Gulch)[a].

Date	Al (tot., %)	Cd (%)	Cu (%)	Pb(%)	Mn (%)	Zn (%)	As (%)
6/7/2006	13	33	42	4239	8	12	248
7/12/2006	135	132	574	57447	66	95	7789
8/24/2006	239	252	1536	153602	120	169	5092
10/23/2006	94	163	255	25543	57	75	1213
6/10/2010	NA	29	50	5046	15	24	209
9/29/2010	33	37	54	5406	14	15	190
6/8/2011	8	3	5	468	4	6	127
9/28/2011	3817	882	1276	127602	1751	2059	3349
5/18/2009	32	35	78	NA	16	27	NA
5/26/2009	11	NA	68	NA	9	14	NA
6/9/2009	39	NA	147	NA	10	46	NA
8/31/2009	NA	NA	NA	NA	14	19	NA
5/25/2010	5	3	5	482	1	2	NA
6/1/2010	24	NA	65	NA	11	19	NA
6/17/2010	8	26	62	NA	7	14	NA
6/14/2011	26	19	64	NA	9	16	NA

[a] Percent loading is a ratio of loading at Tiger Tunnel metal loading vs. metal loading at the mouth of Colorado Gulch, under the assumption that Tiger Tunnel discharge reaches the mouth of Colorado Gulch. At times when Tiger Tunnel discharge does not reach the mouth of Colorado Gulch, this assumption and ratio is not valid. The connectivity between Tiger Tunnel discharge and the mouth of Colorado Gulch is questionable outside of the seasonal high flow period.

NA: Not applicable, concentration below detection limit or not quanitified.

Table 9: [a]Predicted (Pr) metal concentrations at the mouth of Colorado Gulch. Predicted concentrations based on complete load removal of Tiger Tunnel discharge. Values are dissolved concentrations unless otherwise noted.

Date	Cd Pr (ug/L)	Cu Pr (ug/L)	Zn Pr (ug/L)	Al Pr (ug/L, tot.)	Pb Pr (ug/L)	Mn Pr (ug/L)	As Pr (ug/L)
6/7/2006	1.09	8.77	96.47	313.2	0.04	139.9	-0.6
7/12/2006	-1.34	-42.80	**12.12*†**	-168.7	-1.1	116.2	-7.0
8/24/2006	-5.51	-79.80	-169.00	-357.6	-1.3	-65.7	-10.1
10/23/2006	-0.88	-10.96	**25.8†**	**16.1***	-0.1	50.5	-1.9
6/10/2010	1.49	9.34	102.63	NA	**0.1***	169.0	-0.8
9/29/2010	0.73	**3.08†**	80.88	84.7	0.2	83.8	-0.2
6/8/2011	7.07	98.81	453.12	1194.2	1.9	546.5	-0.1
9/28/2011	-12.51	-94.00	-2119.35	-6030.7	-1.5	-1892.6	-8.8
5/18/2009	6.30	25.55	447.22	1088.8	NA	655.4	NA
5/26/2009	NA	8.11	243.83	701.2	NA	366.6	NA
6/9/2009	NA	-11.76	128.57	469.8	NA	324.7	NA
8/31/2009	NA	NA	**109.28†**	**18.8***	NA	174.5	NA
5/25/2010	14.75	185.86	937.16	2538.02	6.9	1110.6	NA
6/1/2010	NA	**2.33†**	36.21	77.02	NA	57.8	NA
6/17/2010	2.02	4.87	147.84	141.26	NA	246.9	NA
6/14/2011	4.20	11.50	254.90	565.70	NA	352.3	NA

[a]The removal of metal loading from Tiger Tunnel discharge to Colorado Gulch assumes that the Tiger Tunnel discharge reaches the mouth of Colorado Gulch. At times when Tiger Tunnel discharge does not reach the mouth of Colorado Gulch, this assumption and calculation is not valid. The connectivity between Tiger Tunnel discharge and the mouth of Colorado Gulch is questionable outside of the seasonal high flow period.

* = Measured concentration above chronic TVS, predicted concentration below this value.

† = Measured concentration above chronic toxicity value for trout, predicted concentration below this value.

NA: Not applicable, concentration below detection limit or not quanitified.

Table 10: Measured metal concentrations in Lake Fork. Values are dissolved concentrations unless otherwise noted.

Date	Cd (ug/L)	Cu (ug/L)	Zn (ug/L)	Al (ug/L, tot.)	Pb (ug/L)	Mn (ug/L)	As (ug/L)
5/25/2010	**8.1**	**90.1**	**559.7**	**1153**	<4.3	747.9	<3.5
6/1/2010	<1	<3.3	**31.6**	**67.9**	<4.3	50.1	<3.5
6/17/2010	<1	<3.3	**40.3**	<40	<4.3	58.4	<3.5

Bold values exceed chronic Table Value Standards for Colorado Gulch (see Table 12).

Bold, underlined values exceed acute Table Value Standards for Colorado Gulch (see Table 12).

Table 11: Metal loading (pounds per day) at Lake Fork. Values are based on dissolved concentrations unless otherwise noted.

Date	Cd (lbs/d)	Cu (lbs/d)	Zn (lbs/d)	Al (lbs/d, tot.)	Pb (lbs/d)	Mn (lbs/d)	As (lbs/d)
5/25/2010	1.33	14.69	91.22	187.86	NA	121.9	NA
6/1/2010	NA	NA	17.6	37.7	NA	27.9	NA
6/17/2010	NA	NA	14.2	11.1	NA	20.6	NA

NA: Not applicable, concentration below detection limit.

Table 12: Hardness-based[a] Table Value Standards (TVS) for aquatic life[b] and threshold toxicity values for brown trout[c] in Lake Fork.

	TVS (ug/L)		Trout Tox Value (ug/L)		
Metal	Acute	Chronic	LC50	Acute	Chronic
Cadmium	0.2	0.1	0.58	0.29	0.24
Copper	1.7	1.4	6.6	3.3	3.0
Zinc	21.5	16.3	77	39	47
Aluminum (tot.)	166.2	23.7	NA	NA	NA
Lead	5.5	0.2	NA	NA	NA
Manganese	1431	791	NA	NA	NA
Arsenic	340	150	NA	NA	NA

[a]Values based on average measured and predicted hardness in Lake Fork (10.99 mg/L as $CaCO_3$; range: 1.71 - 20.31 mg/L as $CaCO_3$, n = 3).

[b]Table Value Standards (TVS) from the Basic Standards and Methodologies for Surface Water, Aquatic Life (CDPHE 2011).

[c]Developed by USGS according to Stephan et. al (1985).

Table 13: Theoretical percent metal load at Lake Fork from Tiger Tunnel (Load ratio: Tiger Tunnel/Lake Fork)[a].

Date	Al (tot., %)	Cd (%)	Cu (%)	Pb (%)	Mn (%)	Zn (%)	As (%)
5/25/2010	4	2	4	NA	1	1	NA
6/1/2010	7	NA	NA	NA	3	5	NA
6/17/2010	8	NA	NA	NA	7	12	NA

[a]Percent loading is a ratio of loading at Tiger Tunnel metal loading vs. metal loading at Lake Fork, under the assumption that Tiger Tunnel discharge reaches Lake Fork. At times when Tiger Tunnel discharge does not reach Lake Fork, this assumption and ratio is not valid. The connectivity between Tiger Tunnel discharge and Lake Fork is questionable outside of the seasonal high flow period.

NA: Not applicable, concentration below detection limit or not quanitified.

Table 14: [a]Predicted (Pr) metal concentrations in Lake Fork. Predicted concentrations based on complete load removal of Tiger Tunnel discharge. Values are dissolved concentrations unless otherwise noted.

Date	Cd Pr (ug/L)	Cu Pr (ug/L)	Zn Pr (ug/L)	Al Pr (ug/L, tot.)	Pb Pr (ug/L)	Mn Pr (ug/L)	As Pr (ug/L)
5/25/2010	8.00	87.06	555.72	1113.32	NA	746.4	NA
6/1/2010	NA	NA	30.07	63.42	NA	48.9	NA
6/17/2010	NA	NA	35.71	NA	NA	54.5	NA

[a]The removal of metal loading from Tiger Tunnel discharge to Lake Fork assumes that the Tiger Tunnel discharge reaches Lake Fork. At times when Tiger Tunnel discharge does not reach Lake Fork, this assumption and calculation is not valid. The connectivity between Tiger Tunnel discharge and Lake Fork is questionable outside of the seasonal high flow period.

* = Measured concentration above chronic TVS, predicted concentration below this value.

† = Measured concentration above chronic toxicity value for trout, predicted concentration below this value.

NA: Not applicable, concentration below detection limit or not quanitified.

8.0 Figures

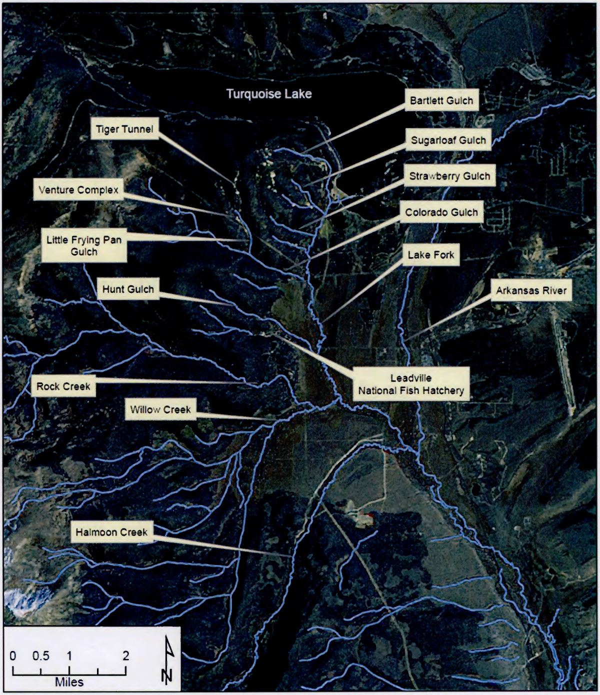

Turquoise Lake
Bartlett Gulch
Tiger Tunnel
Sugarloaf Gulch
Strawberry Gulch
Venture Complex
Colorado Gulch
Little Frying Pan Gulch
Lake Fork
Hunt Gulch
Arkansas River
Leadville National Fish Hatchery
Rock Creek
Willow Creek
Halmoon Creek
0 0.5 1 2
Miles
N

Figure 1: Lake Fork area, Lake County, Colorado.

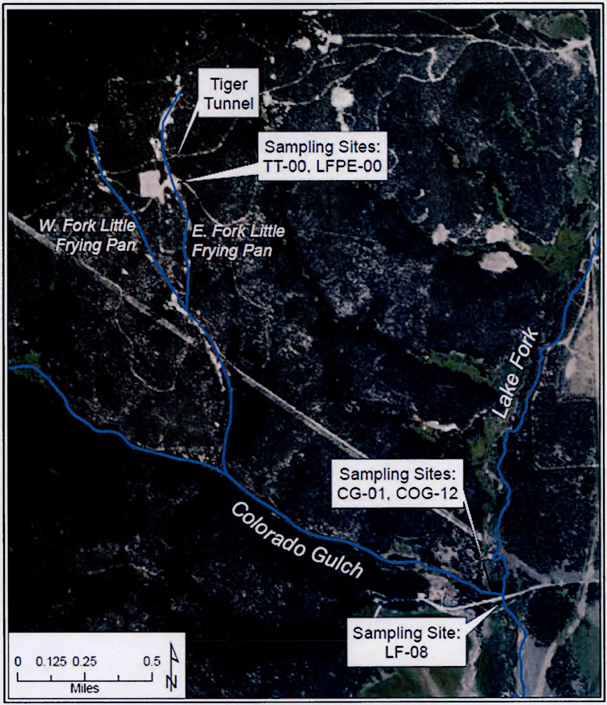
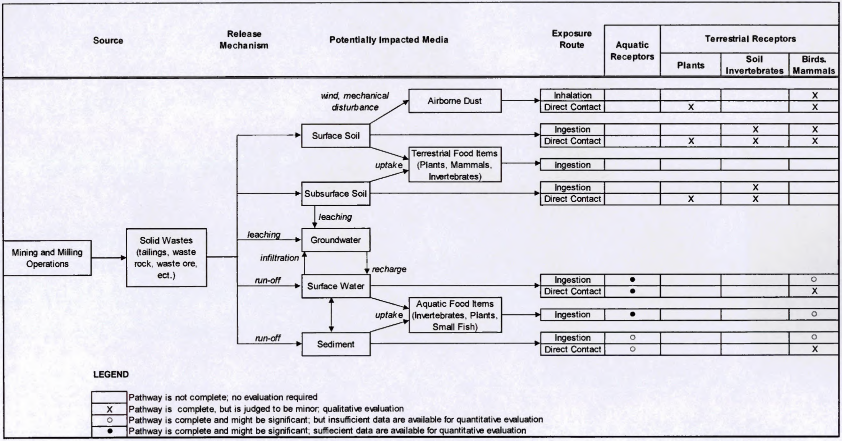

Tiger Tunnel
Sampling Sites: TT-00, LFPE-00
W. Fork Little Frying Pan
E. Fork Little Frying Pan
Lake Fork
Sampling Sites: CG-01, COG-12
Colorado Gulch
Sampling Site: LF-08
0 0.125 0.25 0.5
Miles
N

Figure 2: Tiger Complex area including surface water quality sampling sites..


Source
Release Mechanism
Potentially Impacted Media
Exposure Route
Mining and Milling Operations
Solid Wastes (tailings, waste rock, waste ore, ect.)
wind, mechanical disturbance
Airborne Dust
Surface Soil
uptake
Terrestrial Food Items (Plants, Mammals, Invertebrates)
Subsurface Soil
leaching
leaching
Groundwater
infiltration
recharge
run-off
Surface Water
uptake
Aquatic Food Items (Invertebrates, Plants, Small Fish)
run-off
Sediment

Potentially Impacted Media	Exposure Route	Aquatic Receptors	Terrestrial Receptors		
			Plants	Soil Invertebrates	Birds. Mammals
Airborne Dust	Inhalation				X
	Direct Contact		X		X
Surface Soil	Ingestion			X	X
	Direct Contact		X	X	X
Terrestrial Food Items (Plants, Mammals, Invertebrates)	Ingestion				
Subsurface Soil	Ingestion			X	
	Direct Contact		X	X	
Surface Water	Ingestion	●			○
	Direct Contact	●			X
Aquatic Food Items (Invertebrates, Plants, Small Fish)	Ingestion	●			○
Sediment	Ingestion	○			○
	Direct Contact	○			X

LEGEND

	Pathway is not complete; no evaluation required
X	Pathway is complete, but is judged to be minor; qualitative evaluation
○	Pathway is complete and might be significant; but insufficient data are available for quantitative evaluation
●	Pathway is complete and might be significant; suffiecient data are available for quantitative evaluation

Figure 3: Colorado Gulch and Lake Fork Conceptual Site Model.

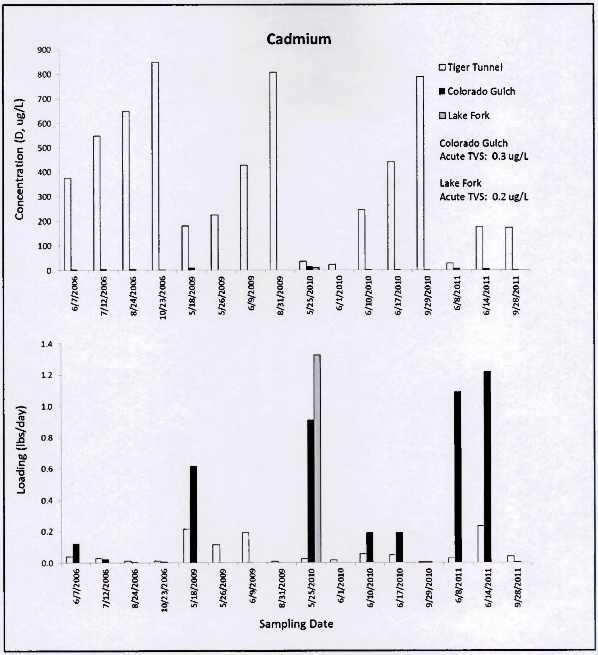


Figure 4: Cadmium concentration and loading data from Tiger Tunnel, Colorado Gulch, and Lake Fork collected from 2006-2011.

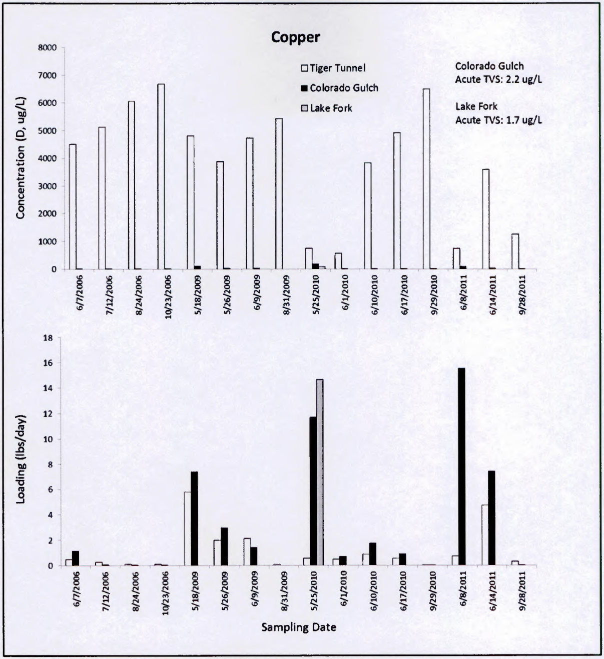


Figure 5: Copper concentration and loading data from Tiger Tunnel, Colorado Gulch, and Lake Fork collected from 2006-2011.

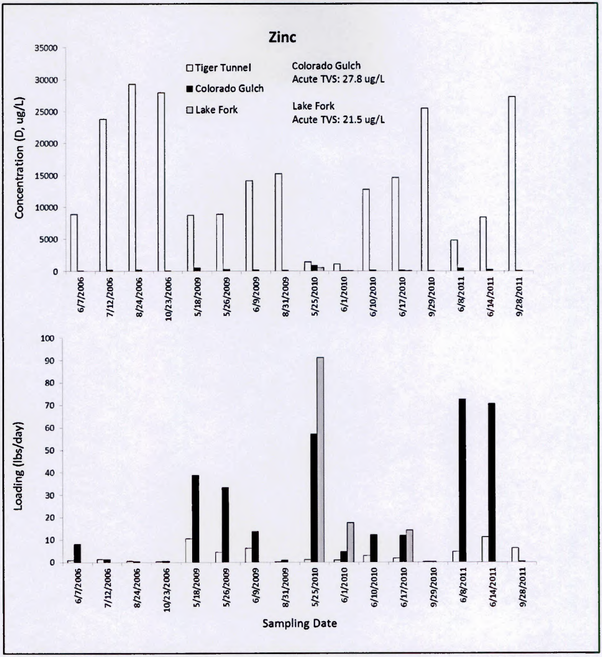


Figure 6: Zinc concentration and loading data from Tiger Tunnel, Colorado Gulch, and Lake Fork collected from 2006-2011.

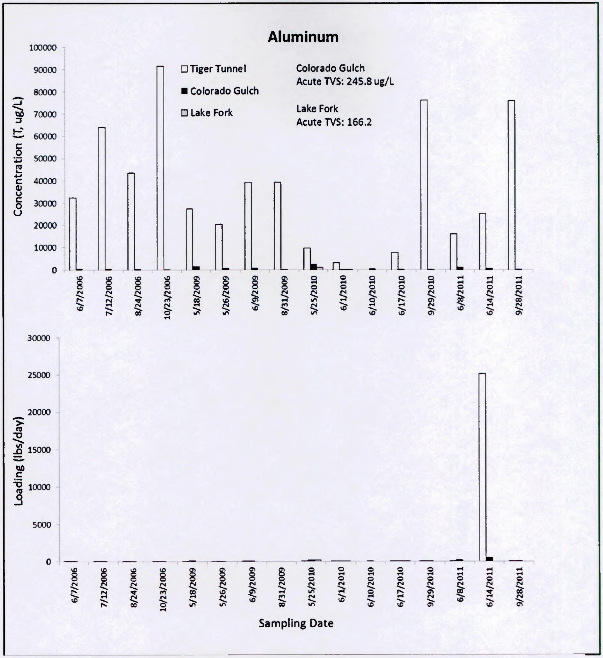


Figure 7: Aluminum concentration and loading data from Tiger Tunnel, Colorado Gulch, and Lake Fork collected from 2006-2011.

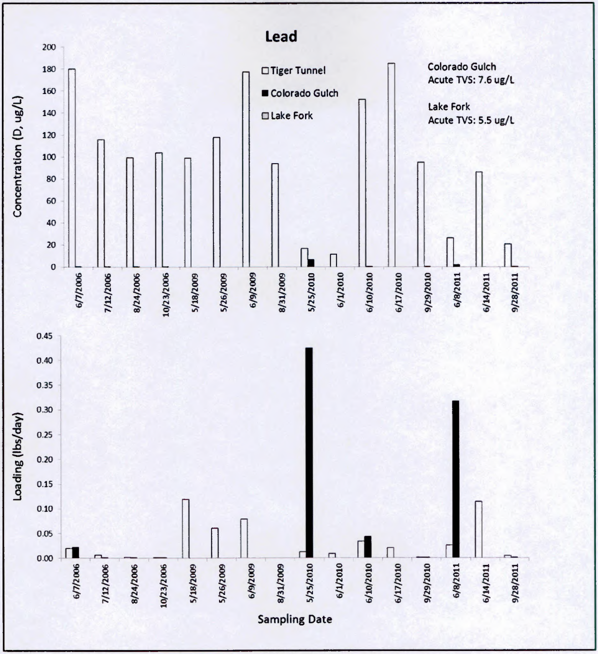


Figure 8: Lead concentration and loading data from Tiger Tunnel, Colorado Gulch, and Lake Fork collected from 2006-2011.

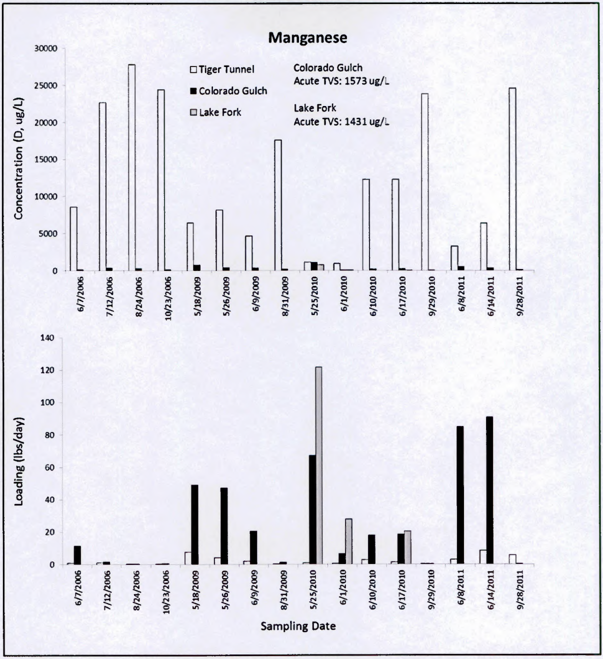


Figure 9: Manganese concentration and loading data from Tiger Tunnel, Colorado Gulch, and Lake Fork collected from 2006-2011.

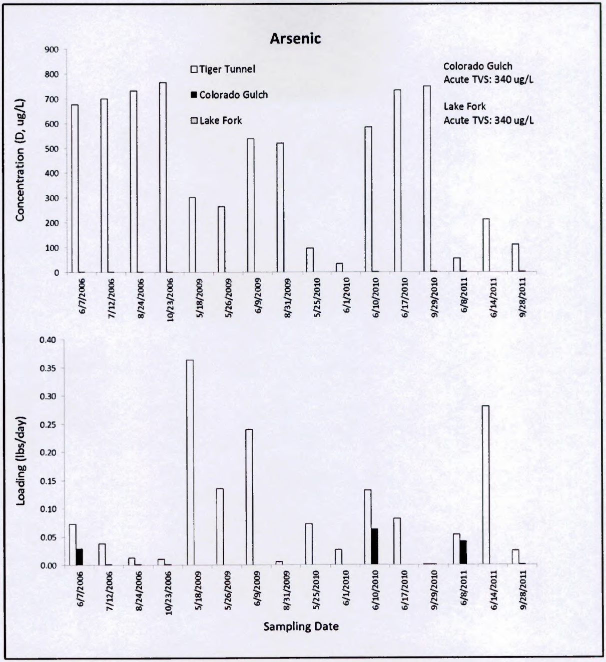


Figure 10: Arsenic concentration and loading data from Tiger Tunnel, Colorado Gulch, and Lake Fork collected from 2006-2011.